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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

INVESTIGATION OF HIGH-PERFORMANCE FUELS IN MULTICYLINDER AND IN SINGLE-CYLINDER ENGINES AT HIGH AND CRUISING ENGINE SPEEDS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

An investigation was conducted to compare the knock-limited performance of a 20-percent triptane blend in 28-R fuel with that of 28-R and 33-R fuels at high engine speeds, cruising speeds, and two compression ratios in an R-1830-94 multicylinder engine.

Data were obtained with the standard compression ratio of 6.7 and with a compression ratio of 8.0. The three fuels were investigated at engine speeds of 1800, 2250, 2600, and 2800 rpm at high and low blower ratios. A carburetor-air temperature of approximately 100° F was maintained for the multicylinder-engine runs. Data were obtained on a single R-1830-94 cylinder engine as a means of checking the multicylinder data at the higher speeds.

A satisfactory correlation between average mixture temperature and knock-limited manifold pressure was obtained by plotting knock-limited manifold pressure against average mixture temperature for the whole range of engine speeds at constant carburetor-air temperature and cylinder-head temperature. The single-cylinder knock-limited performance based on charge-air flow matched that of the multicylinder engine within 6 percent under all the conditions except for 28-R fuel at 2800 rpm; these curves differed from each other by 11 percent in the rich region. The knock rating of 33-R fuel was found to be a little higher than that of the 20-percent triptane blend and 28-R fuel at high mixture temperatures (above 210° F) and lean mixtures. The 33-R fuel exhibited rich

knock limits appreciably lower than the 20-percent triptane blend. Increasing the compression ratio from 6.7 to 8.0 lowered the knock-limited manifold pressure for all fuels approximately 15 to 18 inches of mercury absolute in the cruising range and 20 to 28 inches of mercury absolute at higher engine speeds. Brake specific fuel consumption was reduced 7 to 9 percent by the increase in compression ratio from 6.7 to 8.0.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, investigations have been conducted at the NACA Cleveland laboratory to evaluate the knock characteristics of high-performance fuels. The program included flight determinations in a B-24 airplane (R-1830-94 multicylinder engine), full-scale R-1830-94 single-cylinder determinations, and F-3 and F-4 evaluations of the knock characteristics of triptane blends. Results of the flight investigations are given in references 1 to 3 and the R-1830-94 single-cylinder cooling-correlation data are presented in reference 4. Reference 5 is a summary evaluation of the performance of triptane.

The investigation reported herein was conducted with two compression ratios. The determinations obtained with the standard compression ratio of 6.7 provide a basis of comparison for the determinations at a compression ratio of 8.0. High-compression engines are being considered as a means of using the potential performance of high antiknock fuels inasmuch as full utilization of the qualities of these fuels in currently used engines is usually impractical owing to cooling limitations.

As one of the phases of the fuel-evaluation program, an investigation has been conducted to obtain knock curves for 28-R and 33-R fuels and a blend of 20-percent triptane and 28-R fuel at high engine speeds. Knock data have previously been obtained at cruising engine speeds of 1800 and 2250 rpm (references 1 to 3). Knock data that were obtained in a test-stand R-1830-94 engine and in a single R-1830-94 cylinder engine with the three fuels described in reference 3 (28-R, 33-R, and a blend of triptane and 28-R) are presented; these data extend the range of engine data to 2600 and 2800 rpm.

Inasmuch as this investigation is an extension of the flight investigations, some form of check was needed to establish a correlation between the flight and test-stand results. Data for several knock-limit curves were therefore obtained in runs in which the same carburetor-air temperature and engine-cooling conditions that were set in flight were maintained as closely as possible.

EQUIPMENT AND INSTRUMENTATION

An R-1830-94 engine (No. P-141538) was installed in a cable-mounted test stand and was provided with a standard C-47A cowling. A photograph of the engine and part of the cell and the test-stand equipment is shown in figure 1. Power was absorbed by a 10-foot, 6-inch, three-blade hydromatic propeller equipped with a standard governor.

Power data were obtained from a pressure gage calibrated in brake mean effective pressure, which was actuated by a standard Pratt & Whitney torquemeter. Cylinder temperatures were maintained within close limits by a cooling fan, which drew cooling air over the engine. The speed of the fan was controllable either manually or automatically by variation in the temperature of the hottest cylinder. Individual short stacks permitted atmospheric exhaust conditions.

Engine temperatures were observed and recorded with an indicating potentiometer and a recording potentiometer, respectively. Temperatures automatically recorded were rear-middle-barrel temperature, mixture temperature, and rear-spark-plug-gasket temperature. Rear-spark-plug-boss temperatures were used to control the cooling-blower speed and were manually recorded. A camera was used to photograph the 54-tube manometer board that indicated cylinder-cooling pressures. A calibrated rotameter indicated rate of fuel flow.

Some of the special equipment and alterations to the engine necessary for this investigation are: (1) installation of pressure-type knock-detection equipment in the cylinders and attachment of thermocouples and pressure tubes on each cylinder, as explained in reference 1; (2) installation of an air bleed across the diaphragm of the air-metering chamber of the carburetor, which made it possible to vary the fuel flow in increments smaller than those possible with the standard mixture-control lever; (3) alteration of the front supercharger oil seals (reference 6).

Combustion air was supplied from the laboratory system, which included a unit for control of the carburetor-air temperature, a 6-inch flat-plate orifice for measurement of air flow, and an auxiliary blower that was used when it was necessary to supply carburetor-deck pressures higher than could be obtained at wide-open throttle at a given engine speed.

The single-cylinder test equipment is similar to that described in reference 4, but a high-speed valve gear was so installed in the crankcase that the valves in the single cylinder would more closely follow the action of multicylinder valves at high speeds.

FUELS AND ENGINE OPERATING CONDITIONS

Knock determinations in this program were run on the following three fuels:

Fuel	Rating (reference 7)	
	F-3	F-4
28-R	100	130
20-percent triptane in 28-R (by volume) leaded to 4.6 ml TEL/gal	109	147
33-R	115	145

The two compression ratios employed in this investigation were 6.7 (standard) and 8.0 (with Pratt & Whitney piston No. 40,105). The impeller diameter was 11.3 inches and the impeller-gear ratios were 7.15:1 and 8.47:1. The following engine operating conditions were maintained constant during the investigation:

Spark advance, degrees B.T.C. 25
Inlet-air temperature at carburetor deck, °F. 100
Inlet-oil temperature, °F . . . . 150±5

Cylinder temperatures of the multicylinder engine were controlled according to two different cooling procedures. In the first method, the temperature of the rear-spark-plug boss on the hottest cylinder was held at a constant value of 480° F in order to approximate a rear-spark-plug-gasket temperature of 450° F, which is the maximum allowed by the manufacturer. Sufficient data to check that obtained in flight were obtained by a second procedure used on the multicylinder engine in which the cooling-air pressure drop was held constant for the series of runs that comprised a given knock curve. The pressure drop Δp as plotted on the figures was corrected by the factor $\frac{17.34 \times \text{barometric pressure}}{\text{absolute air temperature}}$, which is denoted by σ.

In the single-cylinder runs, the rear-spark-plug-gasket temperature was held constant at 420° F, which represents the average rear-spark-plug-boss temperature of the test-stand engine at the engine conditions previously listed.

In runs to obtain the knock curves for the multicylinder engine, the fuel-air ratio was varied through a succession of points over a range from approximately 0.055 to 0.10. In order to set a knock point, the manifold pressure and the fuel flow were adjusted until four to six cylinders showed knock on the oscilloscope screens.

Approximately 4 minutes were allowed for engine operating conditions to stabilize before data were recorded; the recording of essential data required approximately 1 minute.

RESULTS AND DISCUSSION

Test-Stand Data

The knock data for the three fuels, 28-R, 20-percent triptane in 28-R, and 33-R, are presented in figure 2; figures 2(a) to 2(e) are arranged in order of increasing supercharger impeller speed and show knock-limited performance at the various engine conditions. Data, which are presented in figures 2(a) and 2(b) and were obtained at 1800 and 2250 rpm, respectively, and low blower ratio, show that with the higher compression ratio the knock-limited manifold pressure was lower than that with the standard compression ratio (6.7) by an average of 15 to 18 inches of mercury. At the higher engine speeds (figs. 2(c) to 2(e)), the difference in knock-limited manifold pressure at the two compression ratios was even greater, that is, 20 to 28 inches of mercury.

The brake specific fuel consumption observed at a compression ratio of 8.0 is compared in figure 3 with that observed at a compression ratio of 6.7. The brake specific fuel consumption was reduced 7 to 9 percent by the increase in compression ratio. Brake specific fuel consumption data observed at two spark advances, 25° and 32° B.T.C., are compared in figure 3(c). The use of a spark advance of 32° B.T.C. resulted in brake specific fuel consumptions lower than that with standard spark advance (25° B.T.C.) at fuel-air ratios below 0.07 but had little effect on brake specific fuel consumption at fuel-air ratios above 0.07.

Plots of knock-limited manifold pressure against average mixture temperature for both compression ratios and at three fuel-air ratios, 0.090, 0.075, and 0.065 are presented in figure 4. The curves of figure 4 were obtained by cross-plotting knock curves from figure 2 for various engine speeds and blower ratios to obtain, at constant fuel-air ratio, knock relations covering the entire range of mixture temperatures and engine speeds. These plots define fairly smooth curves despite changes in mixture temperature caused by changes in both engine speed and in blower-gear ratio from 1800 rpm, low blower, to 2800 rpm, high blower. Such curves, besides being useful for comparisons among fuels over the entire range of operation, provide an indication of the relative temperature sensitivities where increase in mixture temperature is primarily caused by increase in engine speed and blower ratio at constant carburetor-air temperature.

In figure 4 at severe conditions (high mixture temperatures above 210° F and lean mixtures), multicylinder engine data duplicates the order of F-3 ratings with 28-R fuel low, triptane blend intermediate, and 33-R fuel high. At milder conditions (low mixture temperatures), the F-3 ratings are not indicative of results obtained in these investigations and 33-R fuel exhibited rich knock limits (fuel-air ratio of 0.09) appreciably lower than the 20-percent triptane blend. The F-4 ratings are verified in sequence, if not in magnitude, at a fuel-air ratio of 0.09 over most of the temperature range.

Knock data obtained at 2800 rpm and high blower ratio with 28-R fuel are presented in figure 5. For purposes of this discussion, engine temperature is the temperature of the hottest cylinder head on the engine and maximum temperature is the highest value on the curve of engine temperature plotted against fuel-air ratio. The curves show the difference in knock limit obtained by using two slightly different maximum temperatures (480° and 440° F) in a region where the knock limit is low. This great decrease in knock limit with increased cylinder temperature is an effect that has occurred in these runs only at high mixture temperatures where the knock limit is low at low cylinder temperature and where the small influence of increased cylinder temperature is amplified by the effect of exhaust back pressure. The effect of exhaust back pressure on knock limits has been presented in detail in reference 8. This effect was not encountered in the present single-cylinder investigations.

Knock curves obtained with 28-R fuel at 2250 rpm under two different methods of cooling-air pressure control are shown in figure 6. The first method is that of maintaining the rear-spark-plug-boss

temperature of the hottest cylinder constant at 480° F and the second method is that of holding a cooling-air pressure drop constant at the value that gives a maximum temperature approximately equal to the constant engine temperature used in the first method mentioned. The knock curves obtained with these two cooling methods show little difference over the normal range of fuel-air ratio.

Reproducibility of knock limits was very satisfactory and was unaffected by engine wear over the period of investigation. With the pressure-type knock pickups and equipment used, determination of the slightest trace of knock was possible with great clarity at all engine speeds and good reproducibility was partly a result of the ability to adjust engine operating conditions to the same knock intensity for all points. Engine wear was not a factor in this investigation and after completion of the runs at high compression ratio and high power the general condition of the engine was very good.

Checks of Flight Data

A number of knock curves for 28-R fuel were obtained with the test-stand engine at cooling and carburetor-air conditions intended specifically to check flight data previously obtained with another R-1830-94 engine installed in a B-24D airplane. (See reference 2.)

As an example of a representative check between test-stand and flight data, figure 7 is presented for an engine speed of 1800 rpm and low blower ratio. In contrast to the conditions maintained for most of the curves of test-stand data presented, constant cooling-air pressure drop and a carburetor-air temperature of 90° F were used in the flight investigation. Check curves or points were secured for five flight knock curves, one of which is shown in figure 7; four resulted in satisfactory checks (manifold pressure within 2 in. of Hg absolute) at a fuel-air ratio of 0.065 and all proved satisfactory at a fuel-air ratio of 0.090. For the set of data that did not check at lean mixtures, the flight data unaccountably fell lower than that for the test-stand engine. Later investigations of a similar nature with another model of the R-1830 engine have shown better agreement between test-stand and flight data obtained with the same engine than was obtained for the runs with different engines of the same type.

Comparison with Single-Cylinder Data

Single-cylinder check data were obtained at 2600 and 2800 rpm in an R-1830-94 cylinder mounted on a CUE crankcase. Mixture temperatures were set to duplicate both the high and low blower mixture temperatures of the multicylinder engine at these engine speeds. Single-cylinder data obtained at 2600 and 2800 rpm with mixture temperature adjusted to simulate low-blower-ratio conditions are presented in figure 8 and compared with the multicylinder curves of knock-limited air flow per cylinder, mixture temperature, and rear-spark-plug-gasket temperature at various fuel-air ratios. Multicylinder knock curves are lower than those of the single cylinder in the region between fuel-air ratios of 0.07 and 0.09 but data from the two engines check within 6 percent under all conditions except with 28-R fuel at 2800 rpm where differences of 11 percent were encountered. Differences in fuel-air ratio between cylinders of the multicylinder engine might explain most of these variations between knock curves of the two engines.

SUMMARY OF RESULTS

The knock-limited performance of a triptane blend in comparison with 28-R and 33-R fuels in an R-1830-94 multicylinder engine can be summarized as follows:

1. Data over a wide range of engine operating conditions (1800 rpm, low blower, to 2800 rpm, high blower) provided a satisfactory correlation between knock-limited manifold pressure and average mixture temperature. This correlation was not investigated for variable carburetor-air temperature nor for variation in head temperature.

2. Satisfactory check data were obtained for flight and test-stand engines at the same engine operating conditions. For the set of data that did not check at lean mixtures, the flight data unaccountably fell lower than that for the test-stand engine.

3. The single-cylinder knock-limited performance based on charge-air flow matched that of the multicylinder engine within 6 percent under all of the conditions except for 28-R fuel at 2800 rpm where the performance differed by 11 percent.

4. The knock rating of 33-R fuel was found to be a little higher than that of the 20-percent triptane blend and 28-R fuel at high mixture temperatures (above 210° F) and lean mixtures. The 33-R fuel exhibited rich knock limits (0.09 fuel-air ratio) appreciably lower than the 20-percent triptane blend.

5. For engine-cooling conditions where maximum head temperatures were of about the same magnitude, little difference in knock limits was observed for curves obtained with constant cooling-air flow or with constant cylinder-head temperature.

6. Increasing the compression ratio from 6.7 to 8.0 lowered the knock-limited manifold pressure for all fuels approximately 15 to 18 inches of mercury absolute at cruising speed and 20 to 28 inches of mercury absolute at higher engine speeds.

7. Brake specific fuel consumption was reduced 7 to 9 percent by increasing compression ratio from 6.7 to 8.0.

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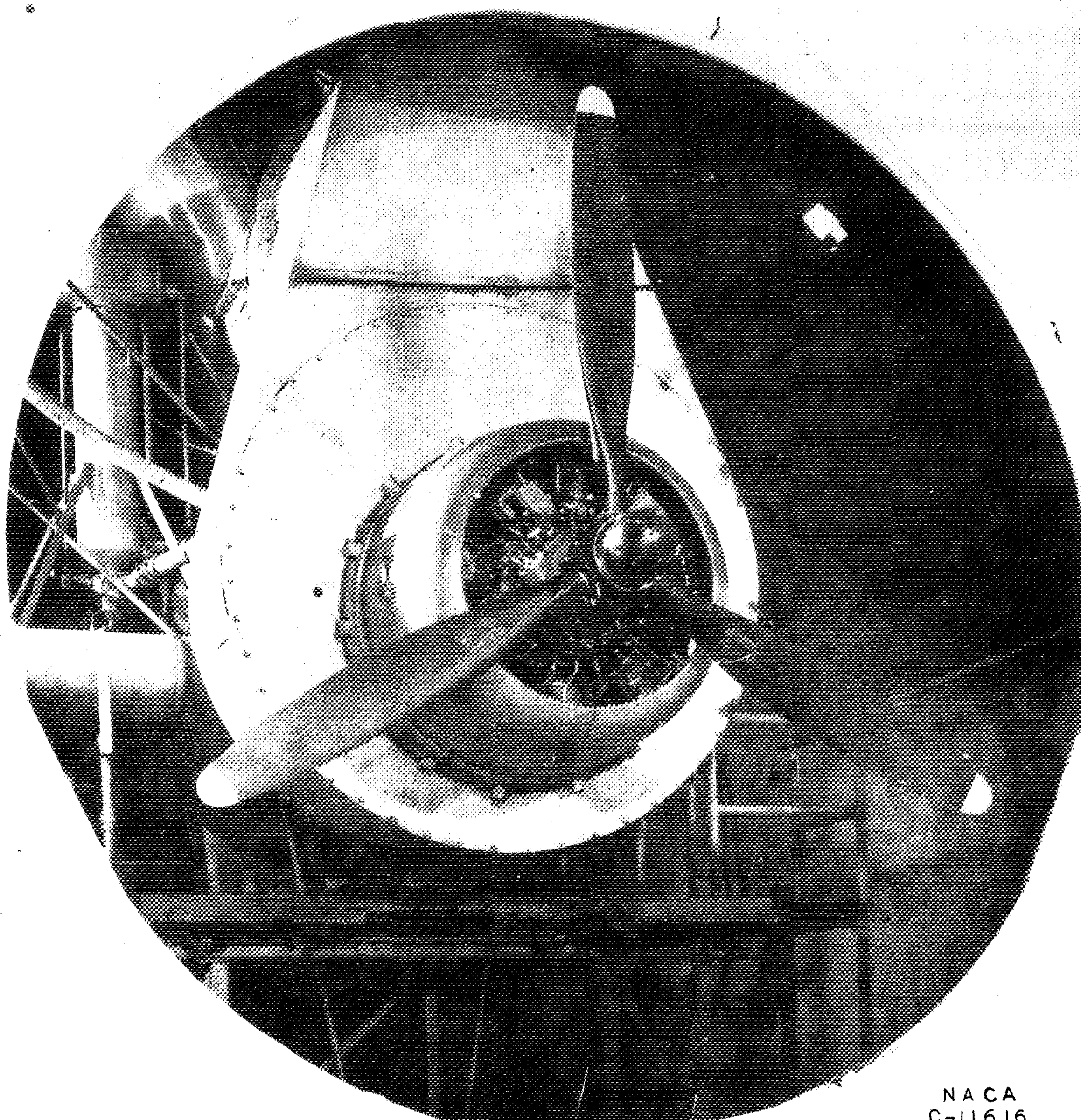
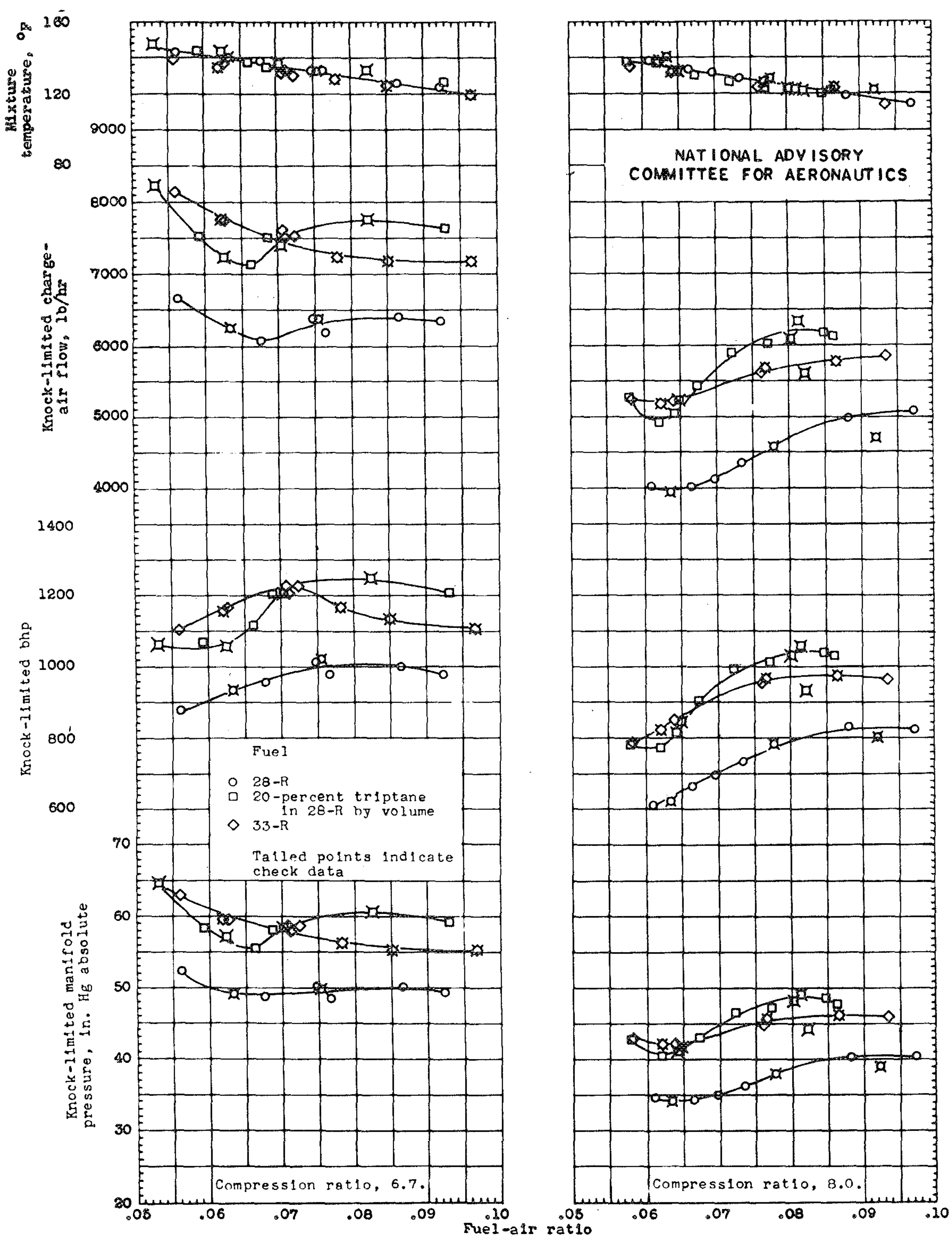
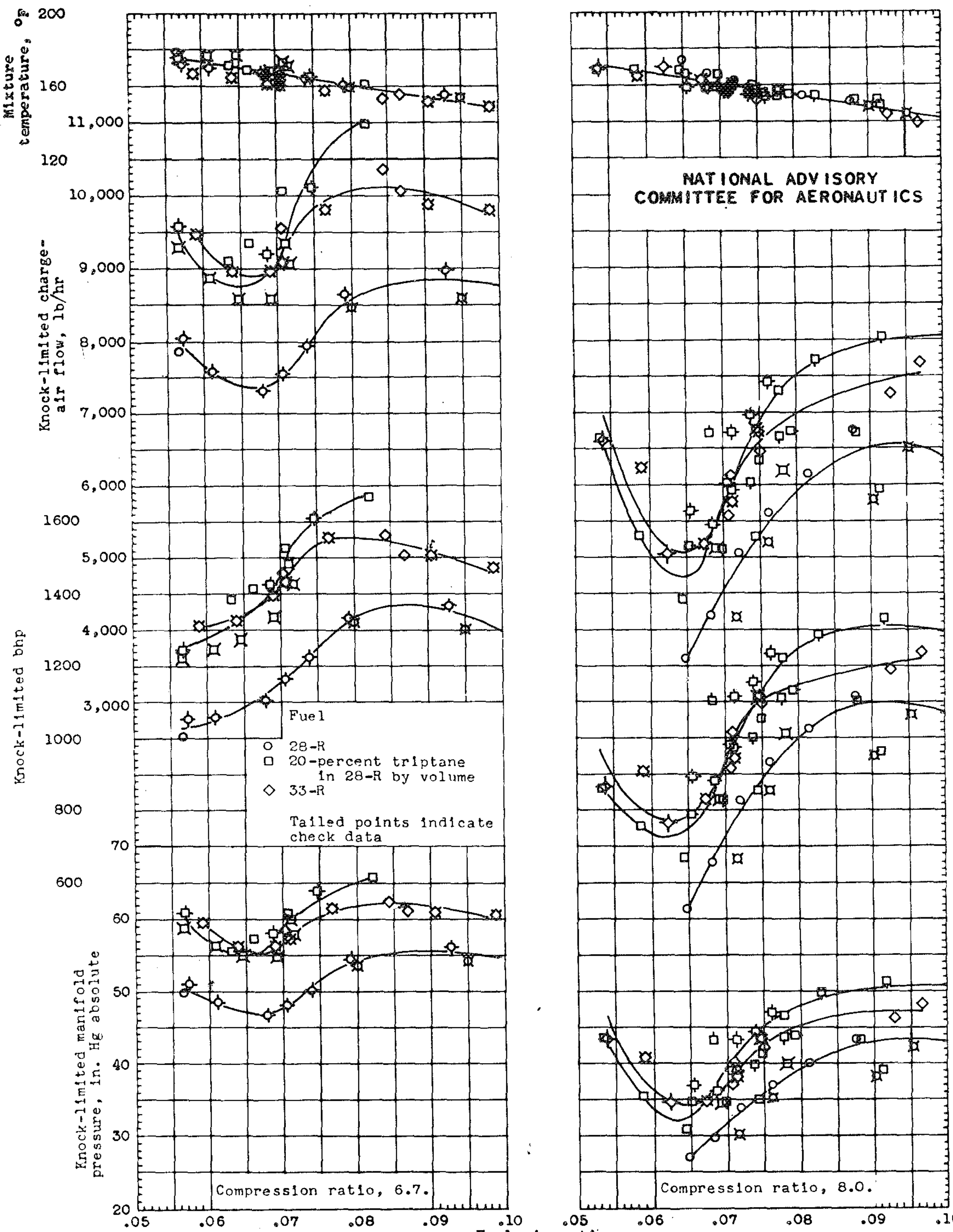


Figure 1. - R-1830-94 multicylinder engine in test stand, showing engine cowling, cooling-air ducts, and part of engine oil system.



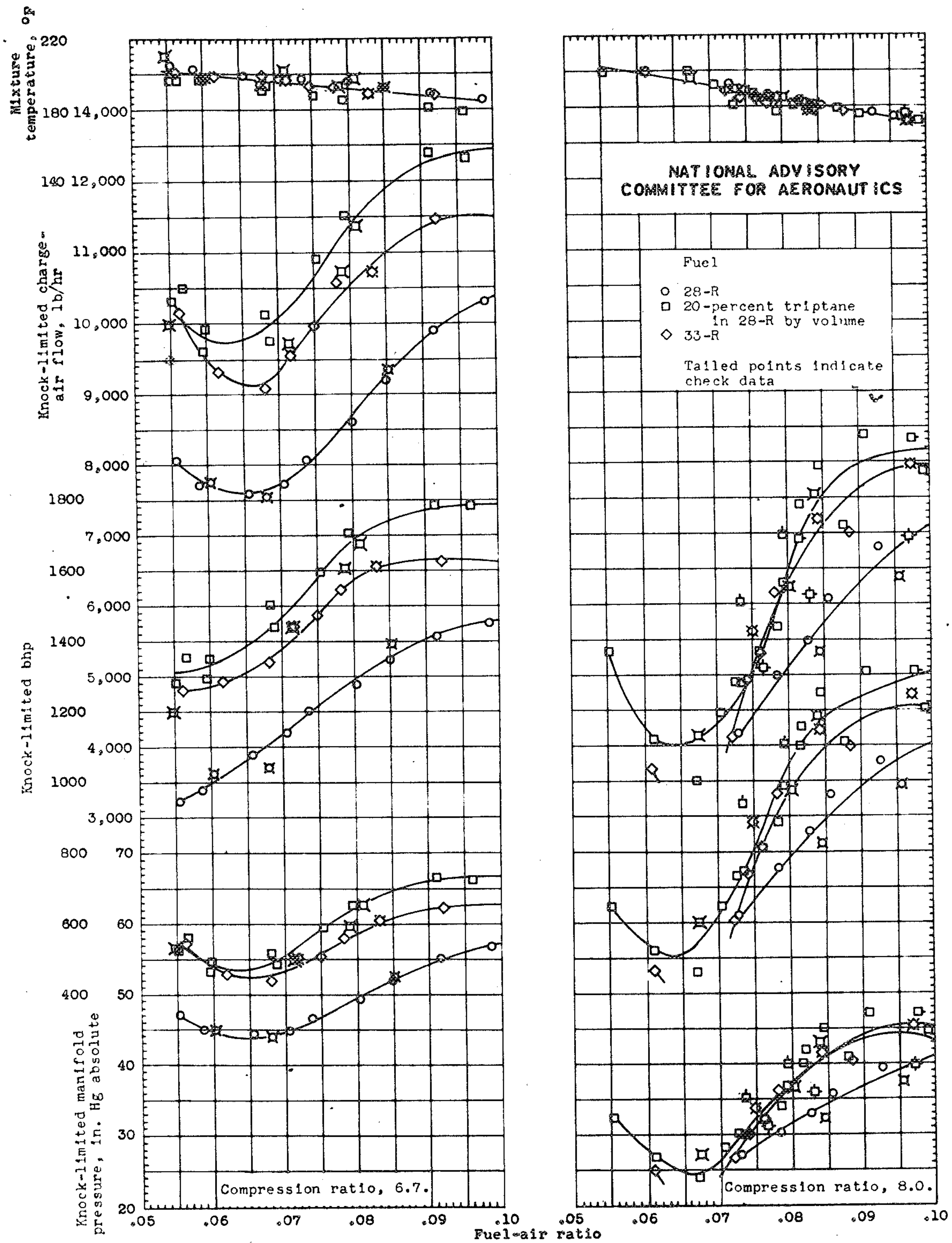
(a) Engine speed, 1800 rpm; low blower ratio; auxiliary boost used at manifold pressure above 40 inches mercury absolute.

Figure 2. - Knock-limited performance of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F; spark advance, 25° B.T.C.



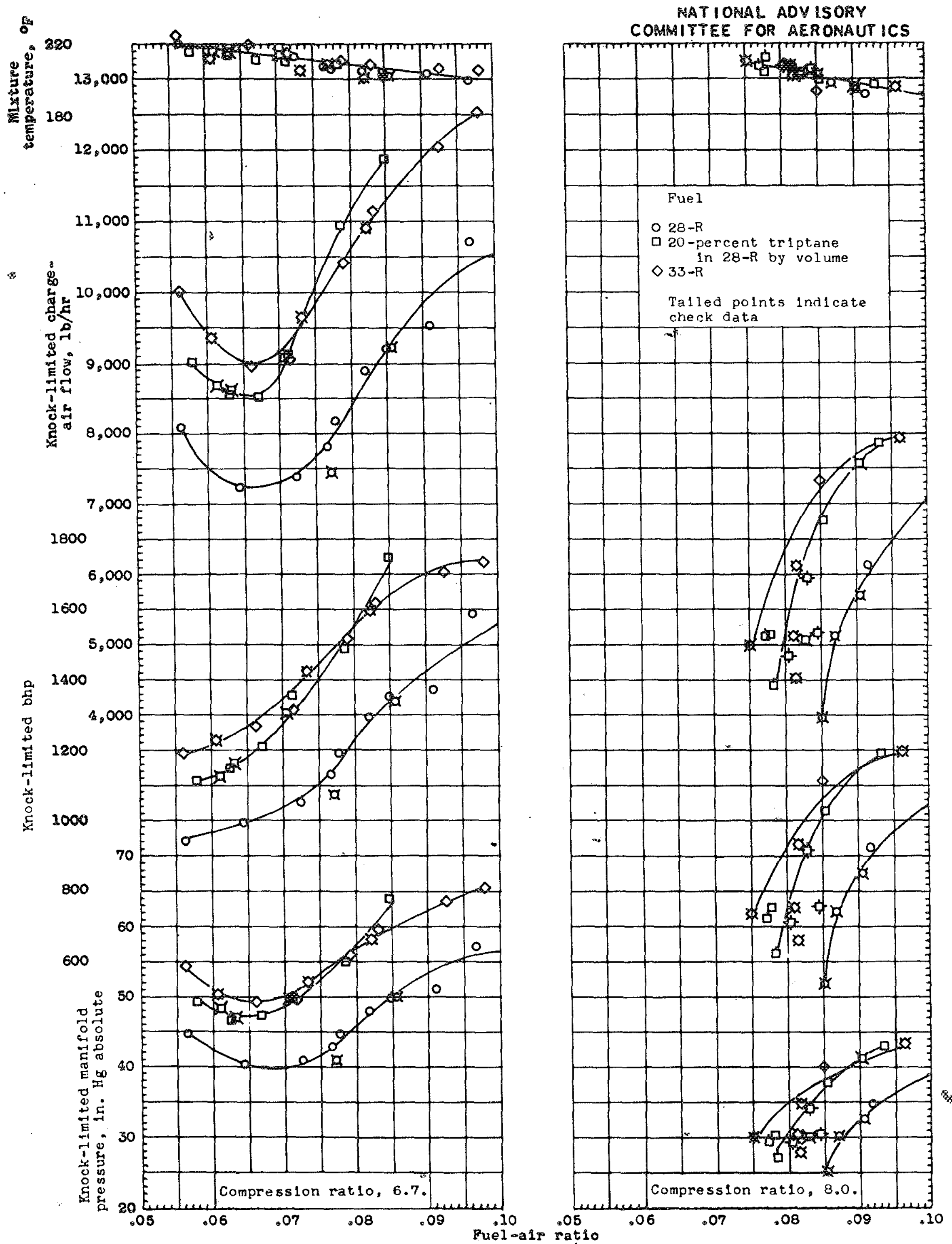
(b) Engine speed, 2250 rpm; low blower ratio; auxiliary boost used at manifold pressure above 45 inches mercury absolute.

Figure 2. - Continued. Knock-limited performance of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F; spark advance, 25° B.T.C.



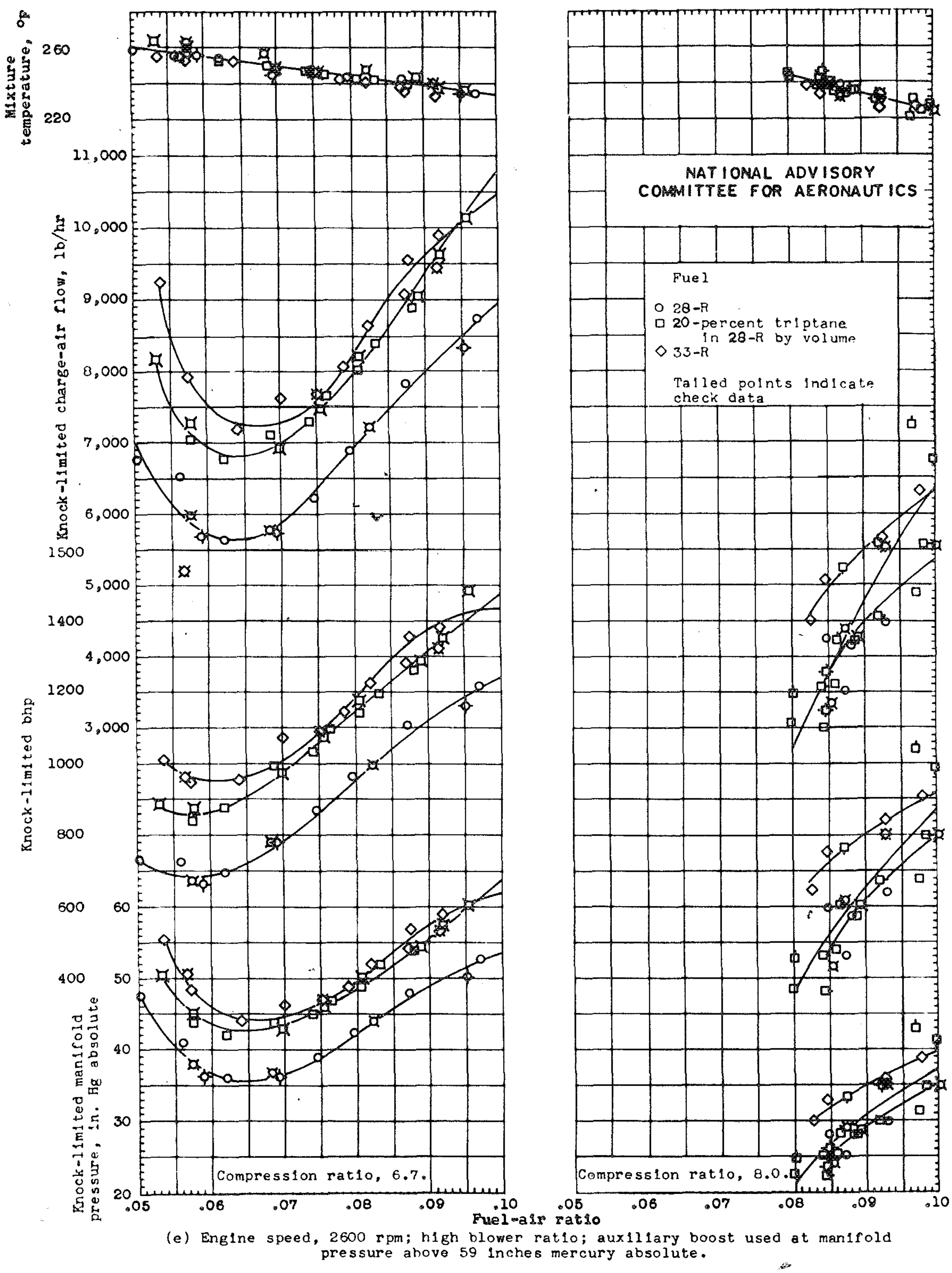
(c) Engine speed, 2600 rpm; low blower ratio; auxiliary boost used at manifold pressure above 47 inches mercury absolute.

Figure 2. - Continued. Knock-limited performance of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F; spark advance, 25° B.T.C.



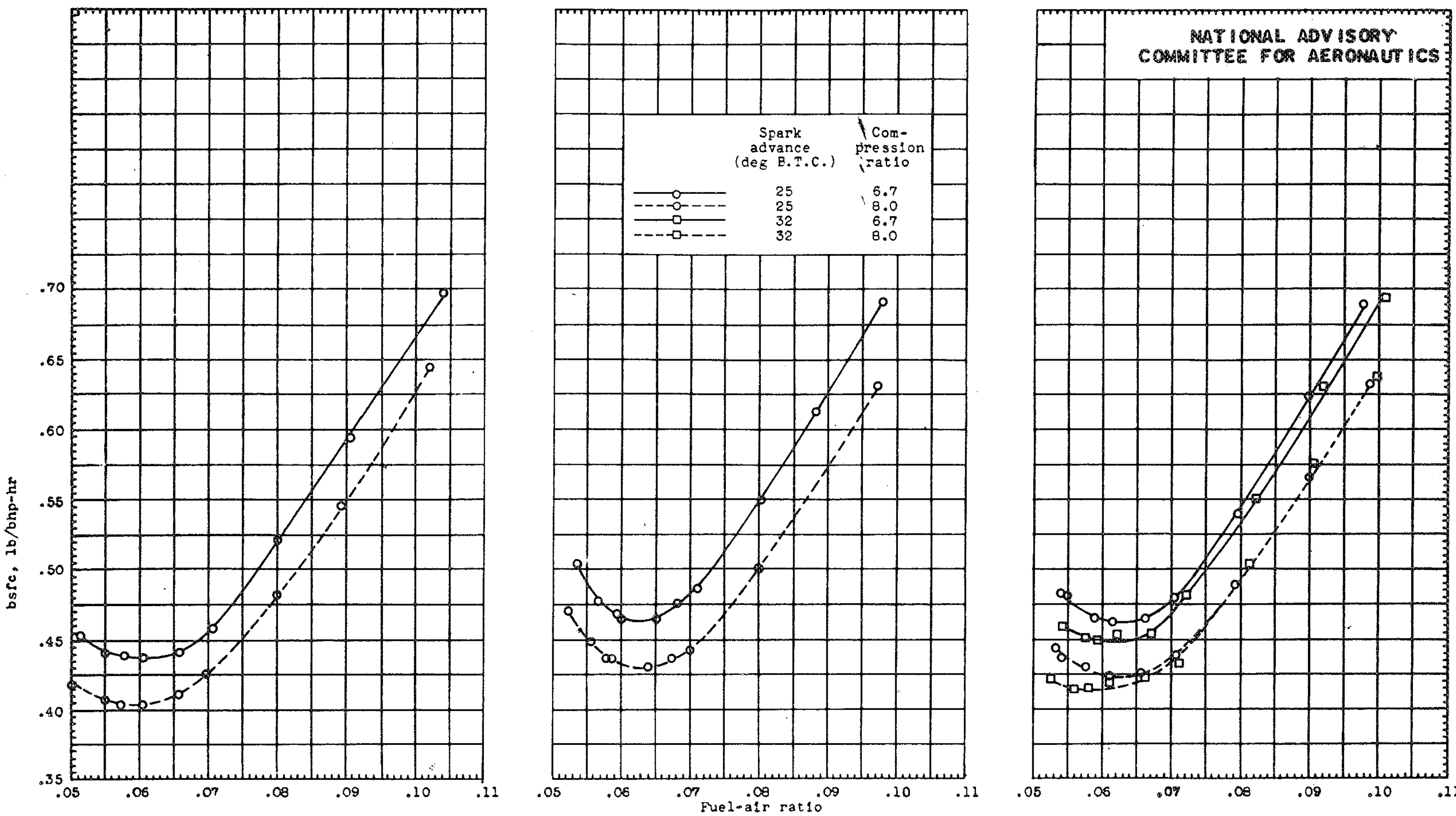
(d) Engine speed, 2800 rpm; low blower ratio; auxiliary boost used at manifold pressure above 50 inches mercury absolute.

Figure 2. - Continued. Knock-limited performance of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F; spark advance, 25° B.T.C.



(e) Engine speed, 2600 rpm; high blower ratio; auxiliary boost used at manifold pressure above 59 inches mercury absolute.

Figure 2. - Concluded. Knock-limited performance of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F; spark advance, 25° B.T.C.



(a) Engine speed, 1800 rpm; high blower ratio; manifold pressure, 40 inches mercury absolute.

(b) Engine speed, 2250 rpm; low blower ratio; manifold pressure, 30 inches mercury absolute.

(c) Engine speed, 1800 rpm; high blower ratio; manifold pressure, 30 inches mercury absolute.

Figure 3. - Effect of change in compression ratio on brake specific fuel consumption of R-1830-94 multicylinder engine. Carburetor-air temperature, 100° F; rear-spark-plug-boss temperature, 480° F.

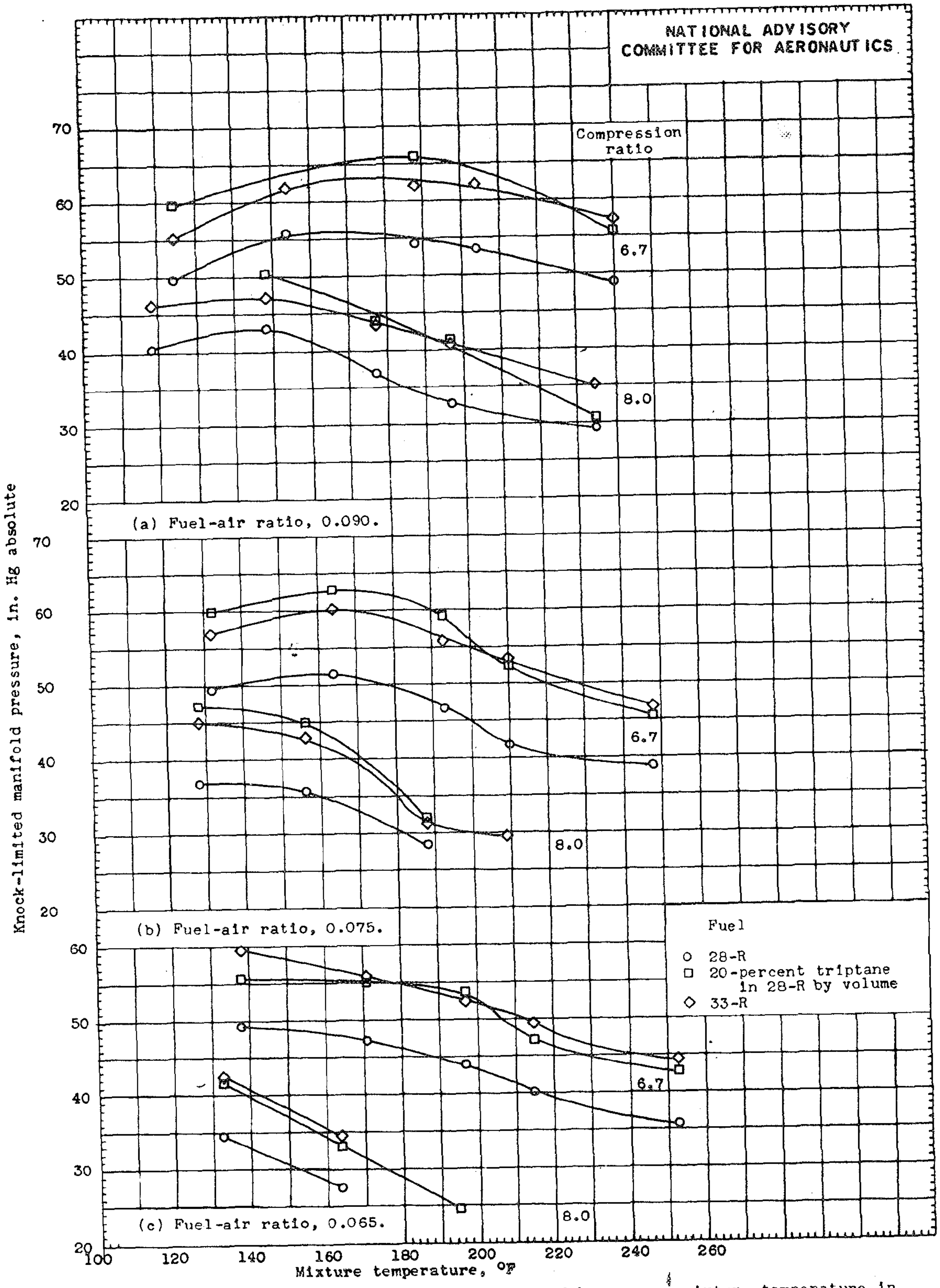


Figure 4. - Knock-limited manifold pressure as affected by average mixture temperature in R-1830-94 multicylinder engine at all speeds and blower ratios. (Cross plot of fig. 2.)

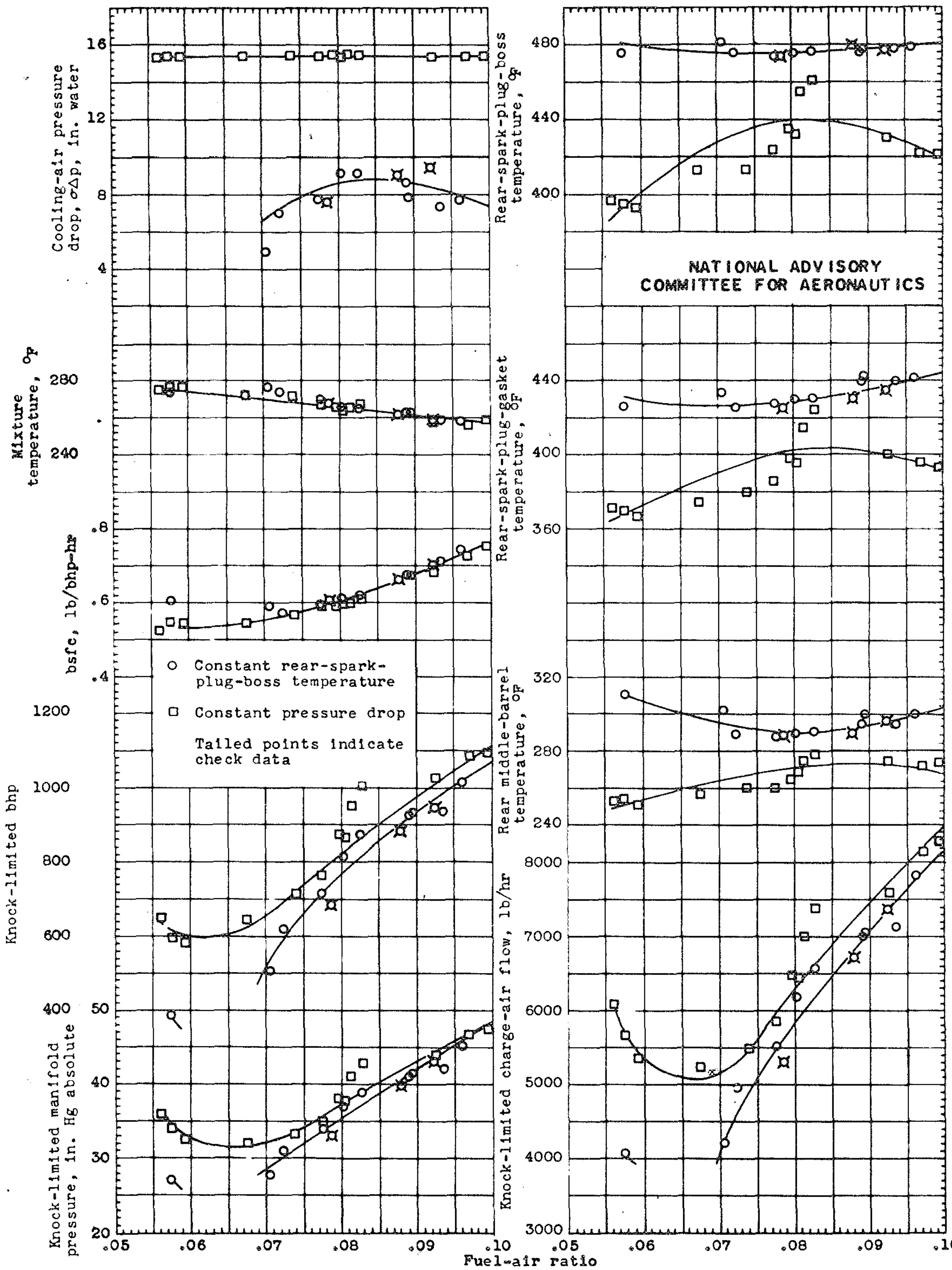


Figure 5. - Change in knock-limited performance of R-1830-94 multicylinder engine caused by change in cylinder-head temperature. Engine speed, 2800 rpm; high blower ratio; carburetor-air temperature, 100° F; spark advance, 25° B.T.C.; fuel, 28-R. No auxiliary boost used.

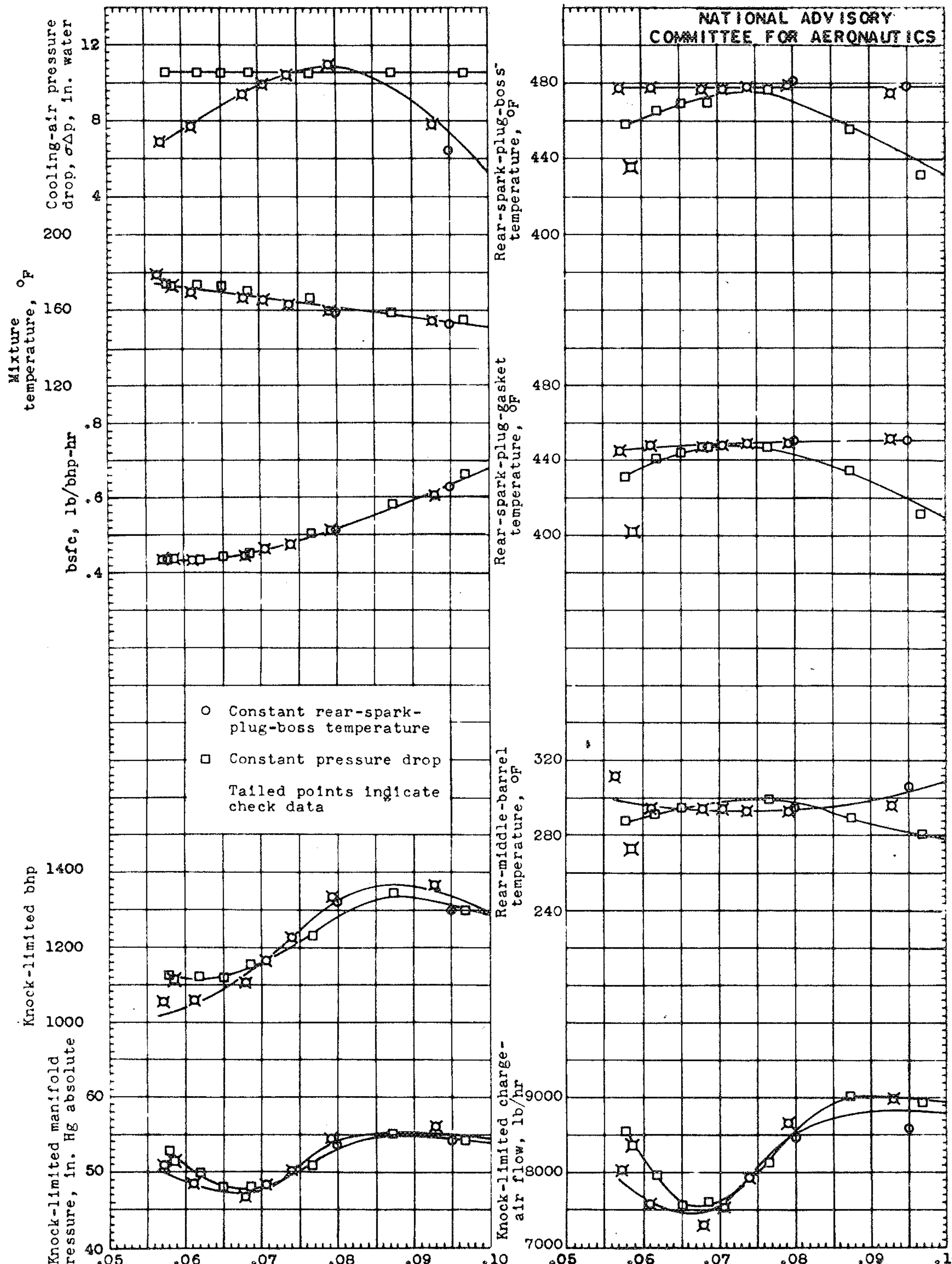


Figure 6. - Effect of different cooling methods on knock-limited performance of R-1830-94 multicylinder engine. Engine speed, 2250 rpm; low blower ratio; carburetor-air temperature, 100° F; fuel, 28-R. Auxiliary boost used at all points.

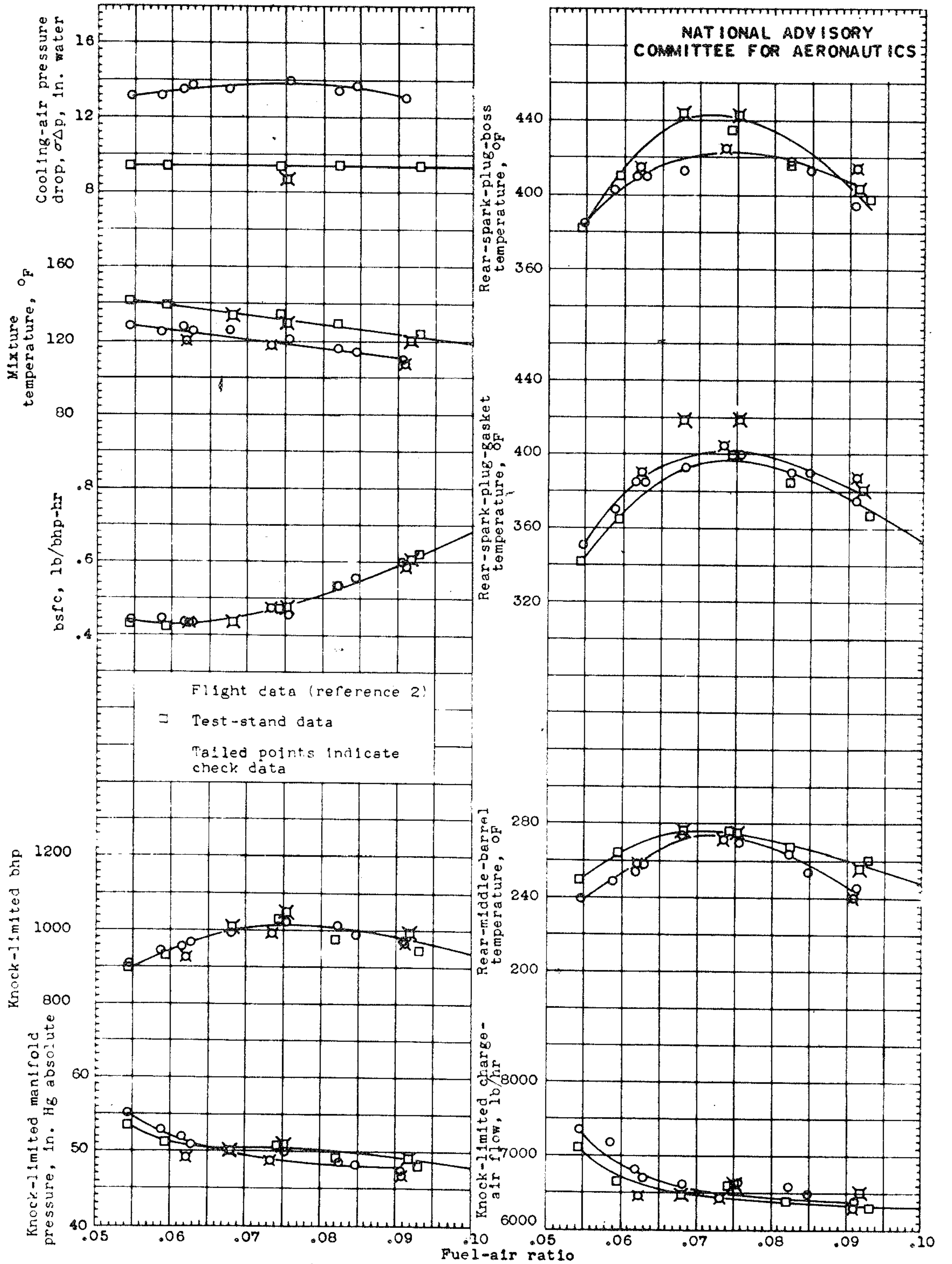
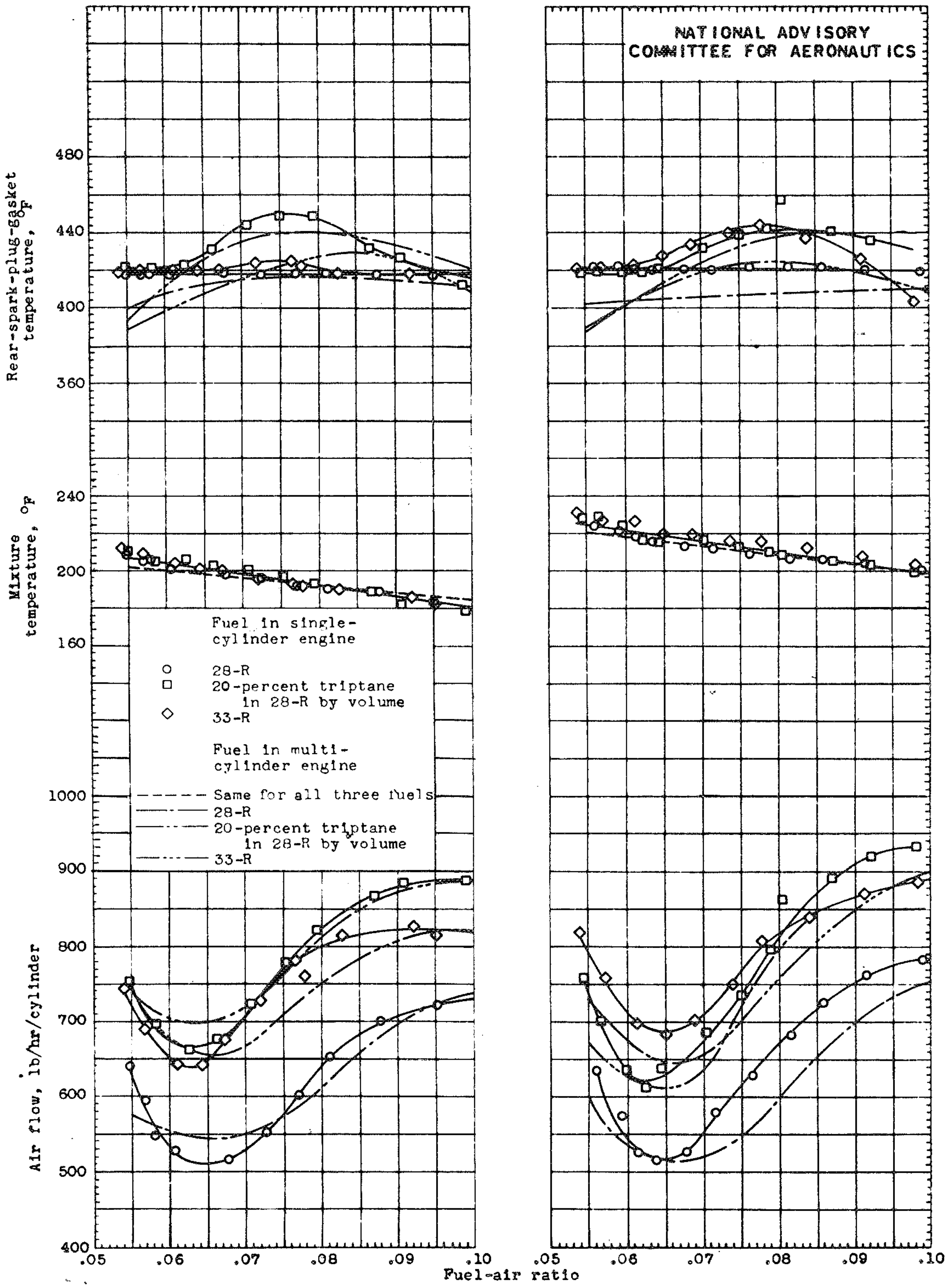


Figure 7. - Comparison of knock-limited performance data obtained with R-1830-94 multicylinder engine on test stand with data taken at the same conditions on similar engine in flight. Engine speed, 1800 rpm; low blower ratio; carburetor-air temperature, 100° F for test-stand engine, 90° F for flight engine; spark advance, 25° B.T.C.; fuel, 28-R. Auxiliary boost used at all points.



(a) Engine speed, 2600 rpm. (b) Engine speed, 2800 rpm.

Figure 8. - Knock-limited performance of R-1830-94 multicylinder engine compared to that of R-1830-94 single cylinder mounted on CUE crankcase. (Multicylinder curves from figs. 2(c) and 2(d).)